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A GAMMA-RAY CAMERA FOR INSPECTION CONTROL

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ABSTRACT

The Research Institute of Pulse Technique has constructed a gamma-ray camera for imaging radioactive materials. The work was performed under the DOE Lab to Lab Dismantlement Transparency Program with the Lawrence Livermore National Laboratory (USA). The gamma-ray camera was intended for imaging radioactive materials, including fissile materials, in a storage container. In this case, the spatial resolution established in the specifications for the gamma ray camera was limited for reasons of inspection non-intrusiveness.

1. INTRODUCTION

In March of 1994, Secretary of Energy O'Leary and Minister of Atomic Energy Mikhailov signed the Joint Statement on Mutual Reciprocal Inspections (MRI). This statement called on both countries to host inspections at facilities storing fissile material from dismantled nuclear weapons. Its unexpected signing set off a two-pronged scramble, in both the policy and technical areas, to determine how to carry out this mandate. During the summer and fall of that year, representatives from U.S. and Russian Federation weapons laboratories met to determine those characteristics of fissile material that could be examined without opening closed containers, to lend confidence (transparency) to the fact that the material had been removed from a dismantled weapon. The experts began by considering only plutonium components, because they are more tractable than highly enriched uranium. Eventually, they decided on the characteristics of isotopic content, mass, and shape to provide confidence in the weapons origin of classified material in closed containers, assuming that some classified information would be allowed to be shared. .

In support of the MRI technical experts' meetings, two technical exchanges were held in the Plutonium Facility at Lawrence Livermore National Laboratory (LLNL). Each side brought candidate technologies for measuring the determined characteristics with minimal intrusiveness, and measurements were carried out on a large number of unclassified plutonium objects of varying shapes. While the two sides rapidly agreed on technologies for measuring mass and isotopics, there was never the same agreement on shape measurements. It became clear during later discussions that it would make each side more comfortable to use imaging apparatus that had been designed and manufactured in the home country, to allow control over the possible inclusion of clandestine elements within the system. In 1995, under the aegis of the U.S. Department of Energy (DOE) Lab-to-Lab Dismantlement Transparency Program, it became possible for LLNL and the Research Institute of Pulse Techniques (RIPT) to collaborate on the design and construction of such a camera to be used for arms control inspections of fissile material, both within and outside of containers. This camera was meant to fulfill most of the conditions described above. The first results of this collaboration are presented in this paper.

2. CONSTRUCTION AND TESTING

The camera construction was based on the approach that was proposed and developed by Professor H. Anger, University of California, in 1953-65. This construction provided adequate (limited) spatial resolution. The design requirements for the camera are given in Table 1.

An external view of the gamma-ray camera developed is given in Fig. 1. A detector with a power supply unit is shown in Fig. 2.

A 312-mm-diameter and 12.5-mm-thick NaI(Tl) scintillating crystal is used as a sensor. The scintillator is viewed by an array of 37 PhEU-184 photomultiplier tubes. The outer surface of the scintillator where the location of the phototube array may be seen is presented in Fig. 3. A honeycomb collimator is attached to this surface for imaging. The electronic circuits (Fig. 4) derive coordinate and energy signals for imaging from the phototube signals.

The data acquisition and processing system, based on a personal computer with the special built-in cards and the software, provides control of the measurement process in the interactive mode and visualizing of the experimental results. The software allows the operator to set the parameters of data-acquisition matrix, required counting, number of frames, acquisition time, and width and position of the spectral ranges. While processing and visualizing, it is possible to get information on the time elapsed from the start of the investigation, counting, gamma-ray energy spectrum and positions of the spectral ranges. The operator can also perform arithmetical operations and image processing, select regions of interest, form profiles of the image, and measure the dimensions of the object under investigation. The software of the gamma-ray camera makes possible acquiring images in a format of 32×32 to 256×256 with up to 256 color or gray gradations.

The study of the main characteristics of the gamma-ray camera and its demonstration to the LLNL representatives were conducted in the RIPT laboratories. The point isotopic gamma-ray sources of 10^4-10^5 Bq activity were used. A source of this kind is shown in Fig. 5. The measured gamma-ray spectrum of ^{57}Co is depicted in Fig. 6. Figure 7 presents the gamma-ray spectrum, recorded while imaging the ^{137}Cs source, with the examples of selection of different gamma-ray energy ranges. An image of two point ^{137}Cs sources located at a distance of 100 cm from the camera is given in Fig. 8. In this case, the spacing between the sources was 10 cm, and the measurement time was 10 min. Finally, the image from an array of five point gamma-ray sources (Fig. 9) is shown in Figs. 10 and 11. In addition, Figs. 10 and 11 display the distributions of the radiation intensity over the given cross sections. The cuts are passed through two sources of approximately equal activity (Fig. 10) and three sources of significantly different activity (Fig. 11).

The experimental results corroborated the main characteristics of the gamma-ray camera:

- The camera is able to record images of objects with dimensions up to 250 mm.

- The intrinsic spatial resolution is better than 5 mm.
- The angular resolution is better than 5°.
- The detected gamma ray energies range from 60 to 510 keV.
- The highest detectable counting rate is $9 \quad 10^4$ g s^{-1}.

3. FUTURE WORK

The camera was shipped to Livermore during the Winter of 1999-2000 following export liscensing. The camera is currently being reassembled at Livermore. Following laboratory tests it will be moved into the plutonium facility and used to image actual weapons and components to develop a data base of information in order to support arms control negotiations. We hope to complete a contract this year for RIPT to complete a second generation camera to be likewise used in a Russian facility.

4. ACKNOWLEDGMENTS

Part of this work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.

Table 1. Design specifications

- Provide search, detection, and localization of weapons-grade plutonium parts in sealed containers.
  – Tuned for radiation the 375 to 415 keV region
- Provide spatial resolution of approximately 1 cm.
- Emanation protection according to the standards for industrial purpose
- Survivability and resistance to external effects
  – Operating temperatures from –10 to +35°C
  – Limiting temperature from –15 to +40°C
  – Operating humidity to 95% at 25°C
  – Survive 10,000 km transport in regular packing
  – Survive 10 shocks of 2 g in regular packing

Figure captions

1. External view of the gamma ray camera during a simulated inspection

2. Main components of the gamma ray camera: the detector and power supply unit.

3. View of the scintillator with the collimator removed. Note the location of the 36-phototube array.

4. Camera electronic unit

5. Sample point source used in the calibrations

6. The measured gamma ray spectrum from ^{57}Co

7. ^{137}Cs spectrum as measured by the camera. Note that images can be accumulated in three separate energy regions.

8. Camera image of two ^{137}Cs point sources located 100 cm from the camera. 10cm separated the sources. The measurement time was 10 minutes.

9. The array of point sources used for spatial testing.

10. Image obtained from the five source array showing a cut through two sources of approximate equal intensity.

11. An array image showing a cut through three sources of different intensities.

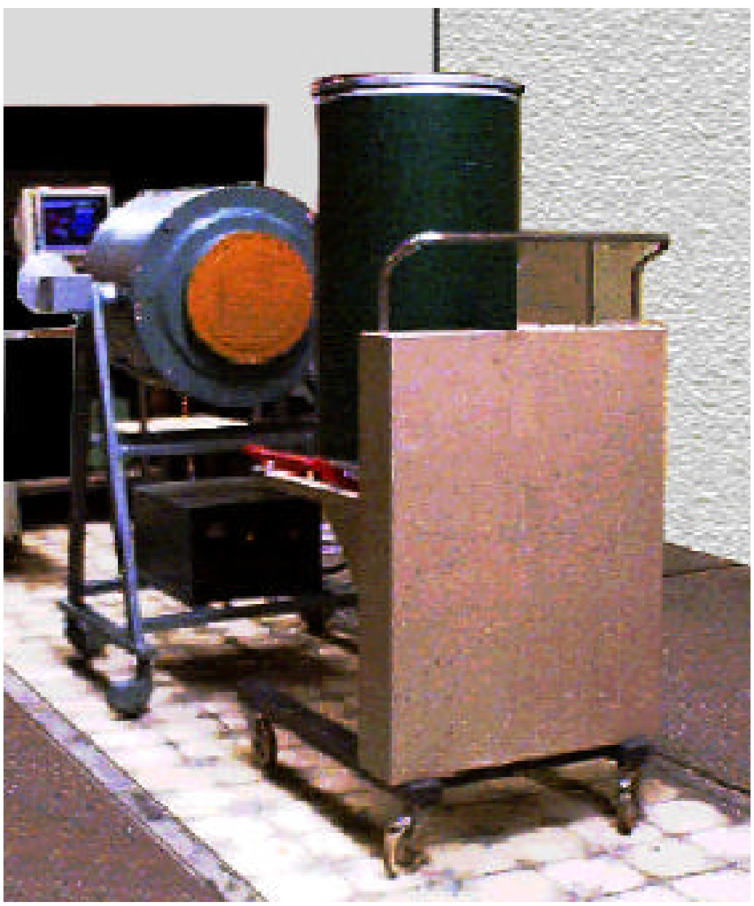
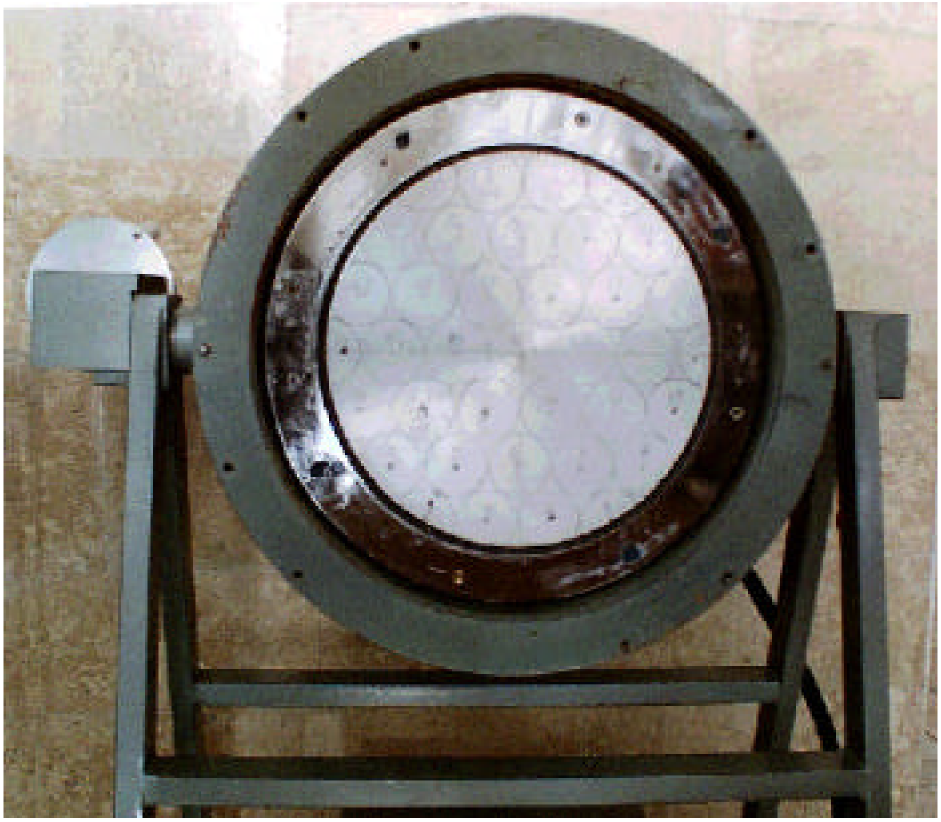


Figure 1

Figure 2



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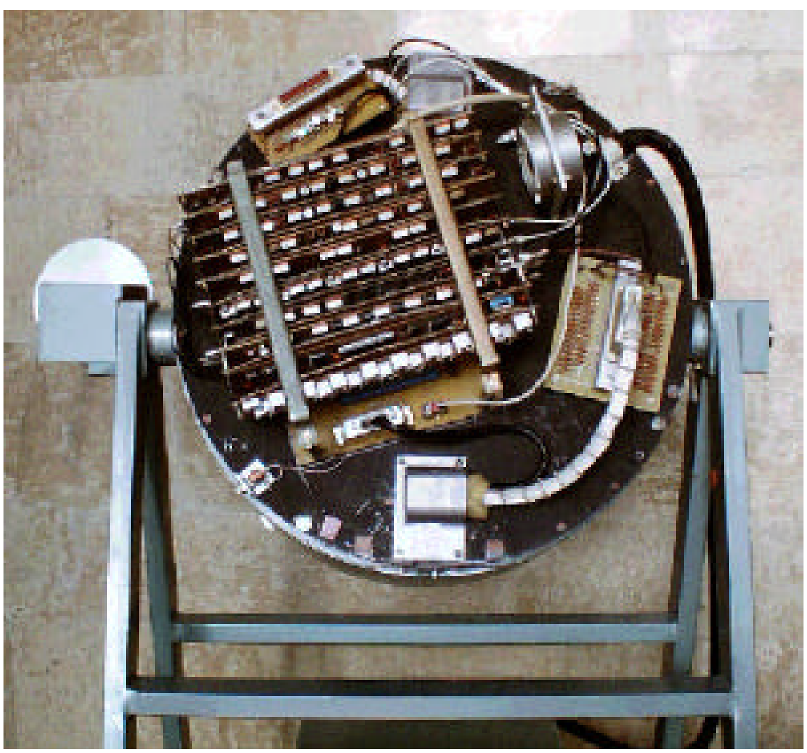

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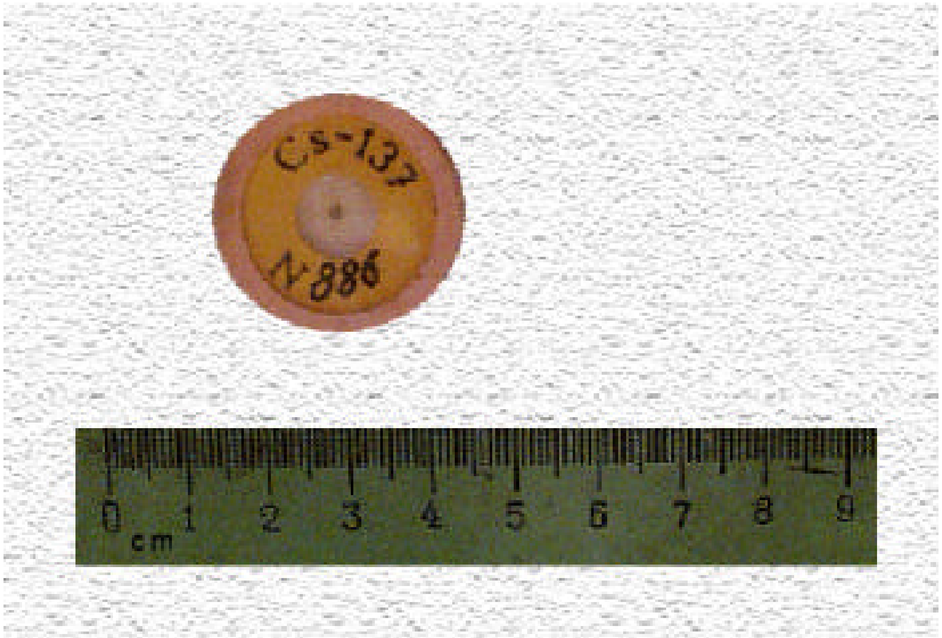

Figure 5

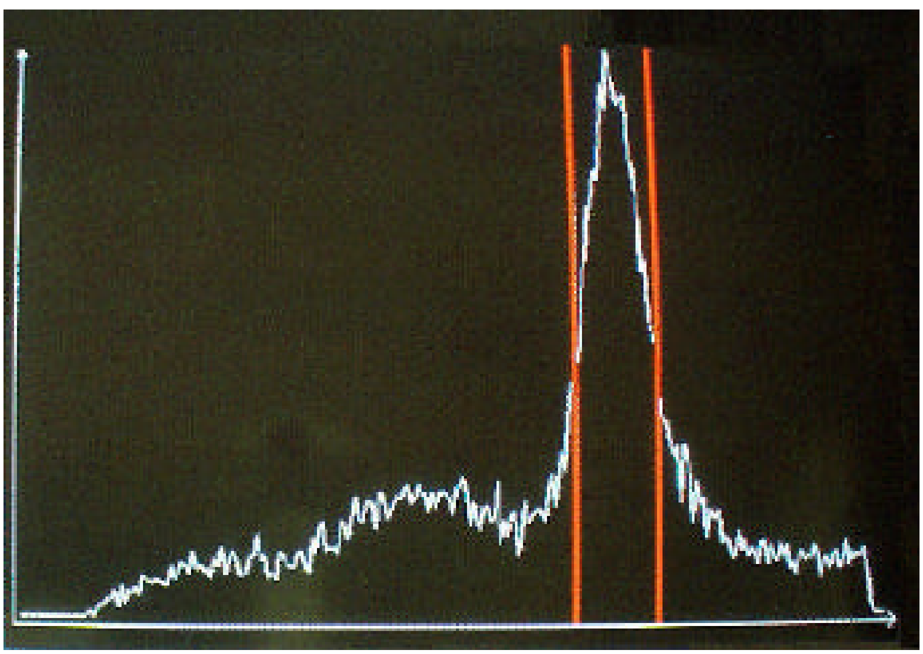

Figure 6

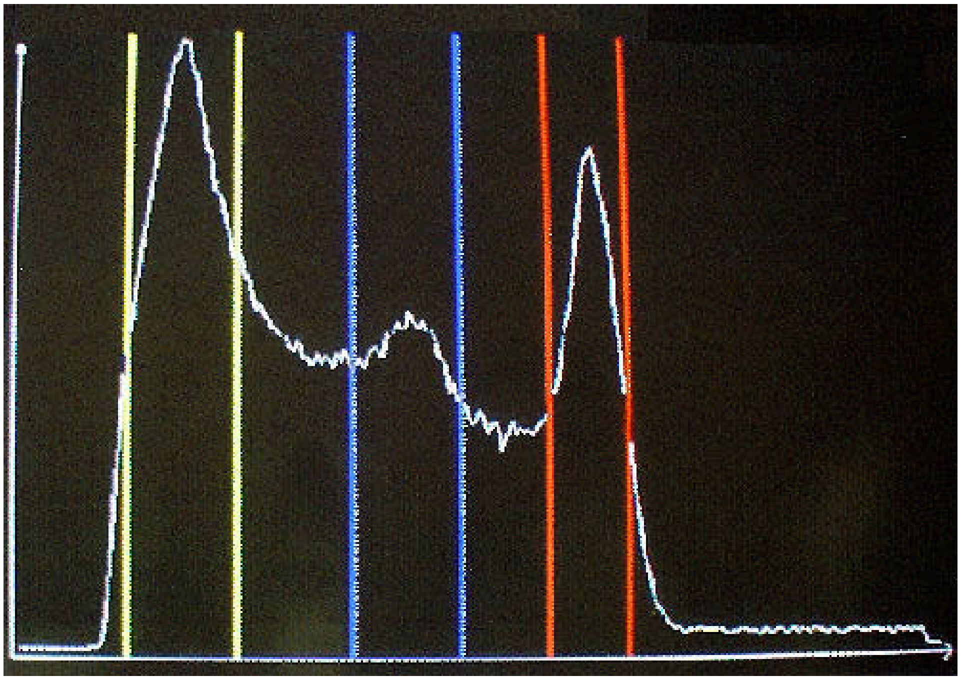

Figure 7

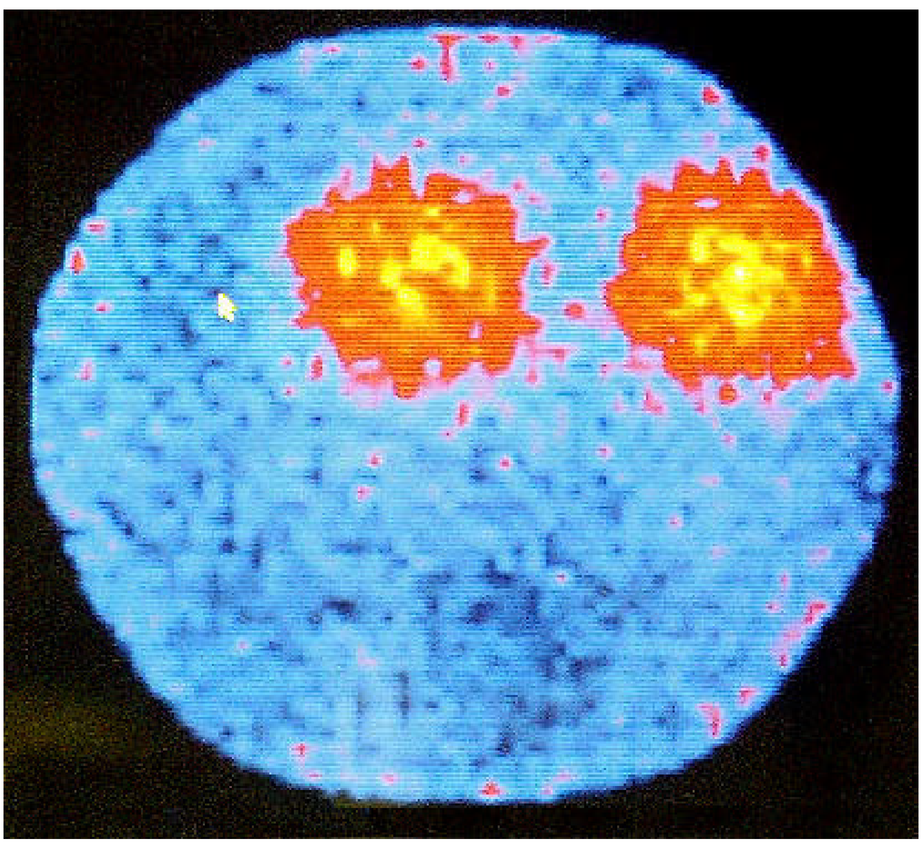

Figure 8

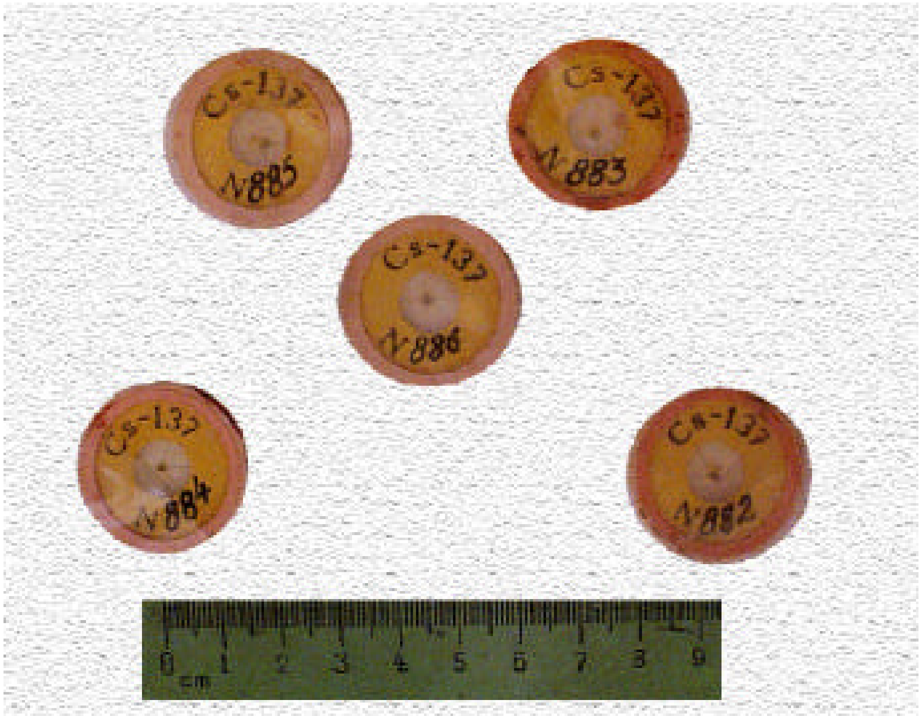

Figure 9

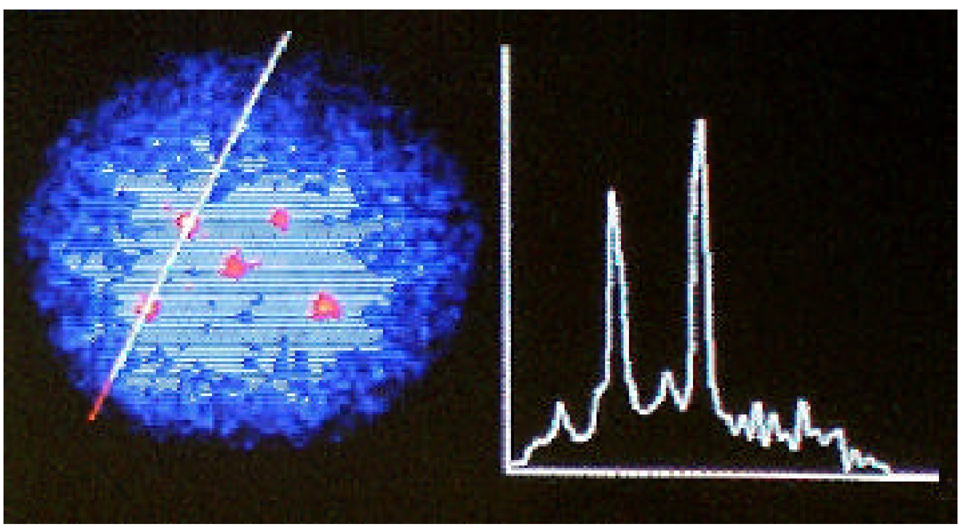

Figure 10

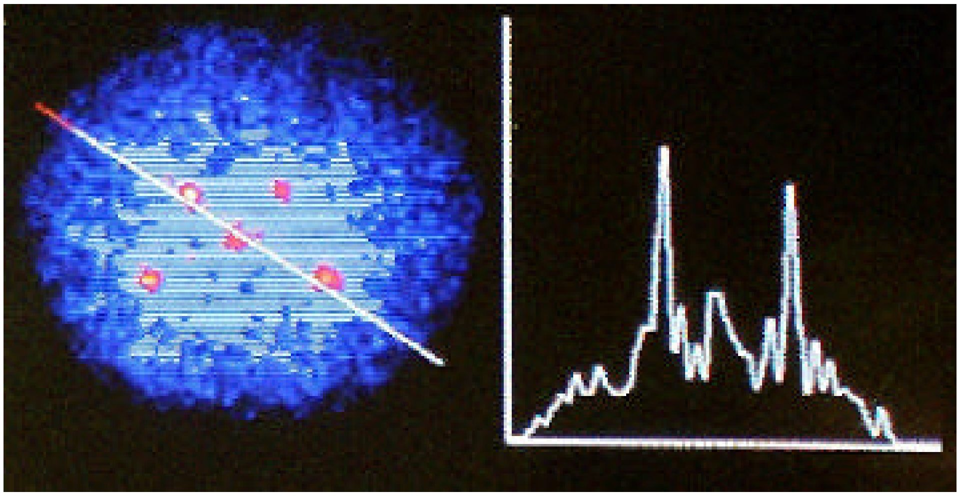

Figure 11